

## CHAPTER 3 OVERVIEW OF NON-*APIS* BEES

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### Introduction

Honey bees (*Apis mellifera* L.) are frequently employed in pesticide toxicity testing either as a representative species (*i.e.*, surrogate) for pollinating insects (such as in the EU) or in other cases to represent other non-target terrestrial invertebrates (such as in North America). As with many surrogate test organisms, there are considerations and/or limitations to using *Apis mellifera* as a representative species for pollinators/terrestrial invertebrates in general. For example, field tests with honey bees can be challenging because of their very long foraging range, the variability of their foraging area and the forage resources they utilize (Visscher & Seeley 1982). In semi-field tests, honey bees do not respond well to being kept in cages or indoor environments for a long period.

Uncertainties also exist regarding the extent to which pesticide toxicity data for honey bees can be considered protective for non-*Apis* bees. Studies have demonstrated variable and inconsistent toxicity among various bee groups (Torchio 1973, Johansen et al. 1983, Malaspina & Stort 1983, Macieira & Hebling-Beraldo 1989, Peach et al. 1994, Malone et al. 2000, Moraes et al. 2000, Scott-Dupree et al. 2009, Roessink et al. 2011). This variability results, in part, from the basic biological differences between the highly social honey bees and other non-eusocial species, as well as intrinsic differences in physiology, life cycle, and behavior between any two insect species (Thompson and Hunt 1999).

The need to thoroughly explore pesticide risk assessment for non-*Apis* pollinators is more important now than in the past as many areas around the world are seeing an increasing demand for insect pollination, but a decreasing relative availability of managed honey bees and the consequential rising costs for honey bee pollination services to satisfy the needs of agriculture (Aizen and Harder 2009). As a result, across the globe many farmers are looking to other managed or wild (unmanaged) non-*Apis* bee species, and scientists

are documenting that many crops are pollinated to a significant level by non-*Apis* bees (Garibaldi et al 2013). For example, managed bumble bees (*Bombus* spp.) are increasingly being used to support agricultural/horticultural production. Over 1 million bumble bee colonies of different species were sold worldwide in 2006, primarily for greenhouse fruit and vegetable production (e.g., tomato *Lycopersicon esculentum*), but also increasingly for commercial orchards and seed production (Velthuis & Doorn 2006).

In the U.S., many growers of alfalfa seed (*Medicago sativa*), almond (*Prunus dulcis*), apple (*Malus domestica*), blueberry (*Vaccinium* spp.), and sweet cherry (*Prunus avium*) are using managed solitary bees such as wood-nesting alfalfa leafcutting bees (*Megachile rotundata*), and blue orchard bees (*Osmia lignaria*), and ground-nesting alkali bees (*Nomia melanderi*). In some places, the use of these non-*Apis* pollinators is already widespread or is becoming more common (Bosch and Kemp 2001). For example, in the U.S. approximately 35,000 tons of alfalfa seed are produced annually with pollination provided by alfalfa leafcutting bees from Canada (Pitts-Singer 2008, Stephen 2003, Mayer and Johansen 2003, James 2011, Pitts-Singer pers. comm. Dec 9, 2011). In Japan, the hornfaced bee (*Osmia cornifrons*) is managed to pollinate orchards of apple and pear (*Pyrus communis*) (Matsumoto et al. 2009), and in Brazil, the carpenter bee *Xylocopa frontalis* can be managed to pollinate the passion fruit (*Passiflora edulis*; Freitas & Oliveira Filho 2003). In Kenya, solitary bees have not yet been commercialized for pollination purposes, but efforts are underway to develop management protocols for solitary bees such as *Xylocopa calens*, *X. incostans*, and *X. flavorufa* for high-value greenhouse crops (Kasina, pers. comm. Oct 5, 2011).

In the tropics, efforts are also underway to develop meliponiculture (stingless beekeeping) as a source of revenue from honey production, other hive products, and rentals for crop pollination. Meliponiculture is well established in countries such as Brazil and Mexico (Nogueira-Neto 1997, Villanueva-Gutiérrez et al. 2005). In Africa there are ongoing efforts to improve the management and expand the use of regionally native stingless bees, for example in Ghana (Kwapong et al. 2010) and in Kenya (Kasina pers. comm. 2011).

At the same time, across the world, there is a growing emphasis on the role of unmanaged or wild bees in agro-ecosystems among agriculture and conservation agencies. For example, in the U.S. this includes national-level ecosystem restoration efforts by the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS), mandated under the *Food, Conservation and Energy Act of 2008* (Vaughan and Skinner 2009). These conservation efforts are based upon general trends demonstrating declines in populations of wild bees in agricultural landscapes (Kremen et al. 2004, Biesmeijer et al. 2006, National Research Council 2007), as well as the increasingly large body of research demonstrating the significant role that unmanaged non-*Apis* bees may play in crop pollination (Kremen et al. 2002, Kremen et al. 2004, Njoroge et al. 2004, Winfree et al. 2007, Campos 2008, Winfree et al. 2008, Kasina et al. 2009, Isaacs & Kirk 2010, Vieira et al. 2010, Carvalheiro et al. 2011). Furthermore, recent research highlights the importance of a diverse pollinator guild for optimal pollination (Klein et al. 2003, Höhn et al. 2008), as well as the benefits of the interaction between honey bees and wild bees to enhance the pollination effectiveness of honey bees (Greenleaf and Kremen 2006, Carvalheiro et al. 2011).

Non-*Apis* bees are often specialized for foraging on particular flower taxa, such as squash, berries, forage legumes, or orchard crops (e.g. Tepedino 1981, Bosch and Kemp 2001, Javorek et al. 2002, Brunet and Stewart 2010). This specialization is usually associated with more efficient pollination on an individual bee visit basis, which can lead to production of larger and more abundant fruit or seed from certain crops (Greenleaf and Kremen 2006, Klein et al. 2007, but see also Rader et al. 2009). In one study, researchers estimated that non-managed bees contribute an estimated US\$3 billion worth of crop pollination annually to the U.S. economy (Losey and Vaughan 2006). More recently, researchers estimated that in California alone, unmanaged non-*Apis* bees pollinated US\$937 million to US\$2.4 billion worth of crops (Chaplin-Kramer et al. 2011). In addition to their impact on agroecosystems, non-*Apis* pollinators are crucial to native flora. More than 85% of flowering plants benefit from animal pollinators (Ollerton et al. 2011), most of which are insects and the most important of which are bees (Apiformes).

Because of the recent increase in our understanding of the value of non-*Apis* bees for agriculture (Garibaldi et al 2013) and the critical role they play in natural ecosystems, researchers have suggested that non-*Apis* bees could play a useful role in risk-assessment for pollinators (Biddinger et al 2013). Recommendations include incorporating at least one solitary managed species, such as the wood-nesting alfalfa leafcutting bees (*Megachile rotundata*) or the blue orchard bees (*Osmia lignaria*) (Abbott et al. 2008, Ladurner et al. 2008), and one managed social non-*Apis* bee, such as bumble bees (e.g., *Bombus impatiens* or *B. terrestris*) in temperate climates (Thompson and Hunt 1999) and/or the highly social stingless bees (e.g., *Melipona* spp. or *Trigona* spp.) in the tropics (Valdovinos-Núñez et al. 2009). To develop appropriate toxicity tests and risk assessment protocols for non-*Apis* bees, however, it is important to understand more about non-*Apis* bees and the unique exposure pathways relevant for them.

### **Non-*Apis* Bee Biology and Diversity**

Worldwide, there are over 20,000 recorded species of bees (Michener 2007, Ascher and Pickering 2011). They range in size from approximately 2 mm (1/12 inch) to more than 25 mm (1 inch), exhibit a wide variety of foraging and nesting strategies, vary from solitary to highly social, and exhibit other diverse life histories.

Bees use nectar mainly as a carbohydrate source and pollen as a source of protein, fatty acids, minerals, and vitamins. Some species also use other plant resources such as resins, leaves, plant hairs, oil, and fragrances to feed their larvae, build and protect nests, or attract mates (Michener 2007). Because they use plant products during all life cycle stages, they are vulnerable to plant protection products that are present or expressed in pollen and nectar, or that are found in or on other plant resources.

During their life cycle, bees undergo a complete metamorphosis where they develop through egg, larval, pupal, and adult stages. It is only the last of these stages, the adult, which most people see and recognize as a bee. During the first three stages, the bee is inside a brood cell of the nest. The length of each stage varies widely between species

and is often defined by whether the bee is solitary or social (O'Toole and Raw 1999). In the case of solitary bees, each female works alone to create a brood cell, place a mixture of pollen and nectar into it, and then lay an egg on (or more rarely in) the food. Solitary bees may take a year to complete metamorphosis, although it can happen faster *i.e.*, 4 to 6 weeks in those species that have 2 or 3 generations per year. Social bees, on the other hand, take only a few weeks to complete growth and emerge as adults.

The quantity of food provided at the time of egg-laying depends on whether the larvae are mass-provisioned (*i.e.*, all of the bee's food is supplied in the cell at one time), or if the larvae are progressively fed (*i.e.*, the food is delivered in small amounts over time). Most solitary bees mass-provision their brood cells, as do most stingless bees, whereas honey bees and most bumble bees feed their brood progressively.

Female bees of most species have special morphological structures that enable them to carry pollen back to their nests. For example, the tibiae on the hind legs of honey bees, bumble bees, and stingless bees are modified into corbiculae (a flattened, shallowly depressed area margined with a narrow band of stiff hairs) into which the bee accumulates pollen wetted with nectar and packed into place. Other bee species have scopae to transport pollen. Scopae are fringes, tufts, or brushes of hair on their legs, their thorax, or the undersurface of the abdomen. Scopae are used to transport large amounts of pollen, usually in a dry state.

The wide range of life history traits of bees has implications for their exposure to pesticides (Brittain and Potts 2011) and so relevant aspects of their natural history is describe below.

### **Generalist and Specialist Foragers**

Bee species have several strategies for pollen collection. Certain species are considered generalist foragers (polylectic). Generalist foragers include species such as honey bees, stingless bees, and bumble bee species, which gather pollen from a wide range of flower species. Other species are considered specialist foragers (oligolectic) and gather pollen

from a narrow range of plant species that are usually related taxonomically. Specialist foragers however, may gather nectar from a wider range of plants than from which they gather pollen. Examples of oligolectic bees include squash bees (*Xenoglossa* or *Peponapis* spp.), *Macropis* spp., and *Leioproctus* spp., which collect pollen from cucurbits (*Cucurbita* spp.), yellow loosestrife (*Lysimachia* spp.), and geebung (*Persoonia* spp.), respectively. A third category of pollen collectors, of which there are very few species, are those bees which are monolectic. Monolectic foragers are those which feed on pollen from only a single species of plant. For example, *Hesperapis araria*, which only visits flowers of the plant *Balduina angustifolia* (Asteraceae) on the coastal islands of the northern Gulf of Mexico (Cane *et al.* 1996). The life cycle of specialists (oligolectic and monolectic) are normally closely tied to their host plants, with the adult female bees emerging from their brood cells when their main pollen sources are flowering (O'Toole and Raw 1999).

### **Social and Solitary Behavior**

Bees exhibit a wide range of social behaviors, but depending on their interdependency, bees can be broadly divided into two groups, social or solitary.

#### *Social Bees*

Social bees typically live as a colony in a nest with one queen (but occasionally can have more than one queen). The labor of building the nest, caring for offspring, protecting the colony, and foraging for resources is shared among female offspring with greatly reduced reproductive capacity. Only a few species of bees demonstrate highly social (eusocial) behavior. These eusocial species include all species of honey bees in the genus *Apis*, and approximately 400 stingless bee species in the tribe Meliponini. Eusocial bees are found primarily in the tropics and subtropics, with two species, *Apis mellifera* and *Apis cerana*, living in temperate areas. Primitively social (or facultatively eusocial) bees exhibit lesser degrees of eusocial behavior (Michener 2007), where colonies are initiated by queens or dominant females on an annual basis (*e.g.*, Halictidae (sweat bees)). Most remaining bee species, the vast majority, are solitary and while sometimes nest together in great numbers, these gregarious bees do not cooperate (Michener 2007, Cane 2008).

In the world's temperate zones, bumble bees are the best known non-*Apis* social bees. Bumble bees live in colonies, share the work of foraging and nest construction, and produce many overlapping generations throughout the year; and thus, they are eusocial. However, unlike honey bees, bumble bee colonies are seasonal. At the end of the summer, most of the bees in the colony die, leaving only a few fertilized queens to hibernate (usually underground) through the winter. In the spring, each surviving queen will start a new nest, which may eventually grow to include dozens to hundreds of workers, depending on the species. Apart from honey bees, bumble bees are often the first bees active in late winter (foraging at lower temperatures than honey bees) and the last bees active in the autumn (Kearns and Thomson 2001, Goulson 2003).

Most bumble bees are generalist foragers, visiting a wide diversity of flowers. Bumble bees can gather pollen by “buzzing” flowers — holding them tightly and vibrating their flight muscles (with an audible buzz), causing the poricidal anthers to release their pollen. Buzz pollinators are important for ensuring pollination in crops with poricidal anthers such as blueberries, cranberries, and other *Vaccinium* spp., as well as solanaceous plants including tomatoes and eggplants (*Solanum melongena*), but also others such as peppers (*Capsicum annuum*) and strawberry (*Fragaria x ananassa*).

Bumble bees need a suitable cavity in which to nest. Sometimes they build nests aboveground, under a tussock of grass or in hollow trees or walls, but generally they nest underground (Kearns and Thomson 2001). Abandoned rodent burrows are common nest sites, as this space is easily warmed and likely contains nesting and insulating materials, such as fur or dried grass. In this cavity, the queen creates the first few pot-like brood cells from wax secreted by her wax glands, lays eggs, and then forages to provide her brood with pollen and nectar (Goulson 2003). It will take about a month for her to raise this first brood. When this first brood emerges, these bees become workers. They take on the task of foraging and help the queen tend the growing number of brood cells through the summer. At the end of summer, new queens and drones emerge and mate. When the cooler weather of autumn arrives, most of the bees, including the old queen, will die,

leaving only the new, mated queens to find appropriate sites in which to hibernate through the winter (Kearns and Thomson 2001).

Bumble bees mainly occur in temperate areas. However, as the pollination demand for greenhouse crops grows, there have been attempts to introduce bumble bee colonies in other non-native temperate zones. The threats of such introduction may include inbreeding with local bumble bee species, competition with the native bees for food resources, and transfer of pathogens (Oldroyd 1999, Thomson 2004, Stout and Morales 2009), which may result in a decline in the abundance and/or diversity of the native bee community (Dafni et al. 2010) and disruption to the pollination of native plants. In temperate countries, the approach of winter controls the population of these bees through the death of all caste members except newly mated queens. In warmer climates, weather may be more favorable year round and these bees may not diapause, increasing their numbers tremendously within a short duration of their introduction (Beekman et al. 1999, Dafni et al. 2010). Bumble bees therefore, may not be appropriate for providing pollination services in the tropics and thus there is a need to study locally or regionally native stingless bees to provide pollination service for greenhouse crops in the tropics (Slaa et al. 2000, Del Sarto et al. 2005).

### *Social, Stingless Bees*

Stingless bees live in the tropical and southern subtropical areas (Michener, 2007). They live in colonies that number from a few dozen individuals to more than 25,000, and they are active year-round. The colony size and nest architecture are characteristic for each different species. Numerous species can be found in Central and South America. In the Yucatan Peninsula for example, farming of stingless bees for honey and wax was so extensive that European honey bees were not introduced until the 19<sup>th</sup> century (Crane 1992, Vit et al. 1994, Javier et al. 2001).

Stingless bees are generalist foragers, visiting a broad variety of flowers. However, individual colonies or populations may demonstrate a tendency to visit particular types of flowers or exhibit a temporary fidelity to specific plant species (Ramalho et al. 1994,



1998, 2007). They are known to visit at least 90 crop species and are used to enhance pollination in some crops on a commercial to semi-commercial basis (Heard & Dollin 1998a, Heard 1999).

Most stingless bees nest in a cavity. Typically, these cavities are in trees or hollow logs; however, a few species will move into termite mounds, building walls, or even cavities underground. Nests are often located 2 to 30 m aboveground (Kajobe 2007). Stingless bees line their nest cavity with an envelope of batuman, a tough mixture of wax produced by the bees combined with resins, gums, plant material, and sometimes mud collected from around the nest. The nests are composed of many storage pots of honey and pollen and smaller brood cells. The pots (both storage and brood) are made of cerumen, a mixture of wax and plant resins.

Within the nest, each brood pot is mass provisioned with hypopharyngeal gland secretions, pollen, and honey. An egg is laid on top of these provisions and then the pot is sealed. The nests can have one to several queens depending on the species. Most species of stingless bees have brood cells of two different sizes; the large cells produce gynes (queens) while the small ones produce males and workers (Michener 1974). Caste determination is usually through food provisioning, with the quantity, not the quality, of food determining the caste. Thus gyne cells are provisioned with more food compared to the worker and male brood cells. This is in contrast to the honey bee caste determination where both quantity and quality of brood food are important.

New nests are initiated on a progressive basis. A virgin queen moves into a new cavity with some workers over a period of several weeks. They take materials from the old nest to create the new nest. Hence stingless bees are not capable of long distance migration (Roubik 2006). However, with domestication, new colonies can be established through methods similar to splitting honey bee colonies. Young gynes are moved together with brood, workers, and males to another hive to establish a new colony (Nogueria-Neto 1997, Arzaluz et al. 2002, Villanueva-Gutiérrez et al. 2005, Kwapong et al. 2010).

### *Solitary bees*

The vast majority of bee species in the world are solitary. For these solitary species, the labor of nest construction and provisioning, foraging and egg-laying is all done by single, fertile female bees.

A female solitary bee may lay twenty or thirty eggs in her life. For solitary species having one generation per year, one to three weeks after an egg is laid, it hatches and the larva emerges to feed on the combination of pollen and nectar (“bee bread”) previously provided by the adult female. The larva grows rapidly for six to eight weeks before pupating. The dormant prepupal or pupal stage typically lasts eight or nine months in temperate climates. When it emerges, the adult bee is fully grown and then needs food (primarily nectar) for egg maturation and energy. Most solitary bees have only one generation per year and have a fairly short season of adult activity. Some solitary species, such as some sweat bees in the genera *Halictus* and *Lasioglossum*, have two or three generations each year and so are present over a longer period of time.

Adult solitary bees are typically active for three to six weeks. Males usually emerge first from the nest, after which they typically loiter around a nesting area or a foraging site in search of a female to mate with. After a female bee emerges, she mates and then spends her time building and provisioning a nest in which to lay eggs (O’Toole and Raw 1999, Michener 2007, Cane 2008). The adults of a species emerge at roughly the same time each year: for example, early spring in the case of blue orchard bees (*Osmia lignaria*) or midsummer in the case of squash bees (*Peponapis pruinosa*). This emergence normally coincides with the flowering of forage plants, particularly if the bee is a specialist.

About 30% of solitary bee species are twig, or wood-nesting. Most species use hollow stems or abandoned beetle burrows or other tunnels in dead or dying standing trees, but some can chew out a nesting tunnel in the soft central pith of stems and twigs, or in a few cases they may bore their own tunnel in wood (Michener 2007). The other 70% nest in

the ground, digging tunnels in bare or partially vegetated, well-drained soil (Potts et al. 2005). Each solitary bee nest will have one or more separate cells in which the female places all the provisions (pollen and nectar) required for the full development of her larvae. While some nests may have only a single cell, most have five or more. In the case of ground-nesting bees, females create a range of underground architectures, from simple tunnels to complex, branching systems with cells usually located 10 cm to 2 m underground. Wood-nesting bees on the other hand, usually stack cells in a single line inside their nest tunnels.

Most wood-nesting species separate individual brood cells with materials they collect, such as leaf pieces, leaf pulp, plant hairs, tree resin, or mud. For example, leafcutting bees (genus *Megachile*) use pieces of leaf or petal to create self-contained brood cells. Using their mandibles, they cut particular sizes and shapes to fit different parts of the brood cell, lining the entire cell. Most other wood-nesting bees, however, do not line the entire cell, but simply build dividing walls across the nesting tunnel, segmenting it into separate brood cells. Blue orchard bees (genus *Osmia*) make these walls with mud or leaf pulp. Large carpenter bees (genus *Xylocopa*) and small carpenter bees (genus *Ceratina*) use wood fibers scraped from the walls of the tunnel to form dividers of compacted sawdust. These bees seal the nest entrance when it is finished with the same materials they use to construct the inner partitions.

Rather than collecting materials from outside the nest with which to line their brood cells, many ground-nesting bee species smoothe the cell walls with their abdomens and then apply a waxy or oily substance produced from special glands near their mouths or on their abdomens to line the cells, thus stabilizing the soil and protecting their brood. The substance lining the cell usually soaks into the soil, making it look shiny and helping to exclude water and control microbes. Plasterer or polyester bees (genus *Colletes*), yellow-faced bees (genus *Hylaeus*), and other bees from the family Colletidae line each cell with a cellophane-like substance secreted from special glands to create a complete waterproof lining for their underground cells. A few species, such as tiny *Perdita* bees living in the southwestern deserts of the United States, leave their underground cells unlined.

### **Status of Toxicity Testing for Non-*Apis* Bees**

In general, the research on pesticide toxicity and risk assessment for non-*Apis* bees lags behind that for honey bees (see Tables 8-2, 8-4, and 10-5 for examples of pesticide toxicity studies conducted on non-*Apis* bees). Except for bumble bees, most of the data referred to on non-*Apis* bees has been sourced from North America. The most commonly studied species are *Megachile rotundata* (the alfalfa leafcutting bee), *Bombus impatiens* (the eastern bumble bee), and *Osmia lignaria* (the blue orchard bee), all of which are managed species of economic importance. These species have been put through a range of lower and higher tier toxicity tests, but only for a handful of active ingredients, usually of regional importance. At present, the tests are not standardized.

Most of the non-*Apis* bee toxicity testing conducted in Europe has been on bumble bees, and in particular *Bombus terrestris*, which is the main species used for commercial pollination. Typically, bumble bee suppliers (e.g., Koppert Biological Systems, Biobest, and Syngenta Bioline) complete thorough higher tier testing of pesticide toxicity to ensure bumble bee safety in greenhouses when pesticides have to be applied. Lower tier toxicity tests (e.g. acute toxicity tests conducted in the laboratory) are somewhat limited, but comparative toxicities between *A. mellifera* and *Bombus* spp. have been reviewed by several authors (Thompson 2001, van der Steen et al. 2008). Comparison has been made both on a dose per bee level and a dose per gram of bee (factoring in the larger size of the bumble bee). The broad conclusions are that there is no consistent correlation between the toxicity for *Apis* and *Bombus* workers, but the general trends suggest that the toxicity to bumble bees is less on a per bee basis and similar on a per gram of bee basis (see also Figures 8-1 to 8-3).

Work on the comparative toxicity of pesticides to individual/colonies of stingless bees in the subtropics and tropics is in its relative infancy. In part, this is because little is known of the biology of most stingless bee species and many species remain undiscovered or undescribed. However, because there is significant interest in the management in these species for the pollination of high value crops, the need to understand the effects of

pesticides is growing. Already some toxicity work has been done using various species of Meliponini (*Melipona beecheii*, *Trigona nigra* and *Nannotrigona perilampoides*; Valdovinos-Núñez et al. 2009). Collaborations are underway between national regulatory authorities, national research institutions, and universities to develop toxicity testing protocols for non-*Apis* bees commonly used for field or greenhouse pollination in the tropics. Using OECD guidelines (OECD 1998) as a template protocol, these toxicity tests are being developed by partners in Brazil, Kenya, and the Netherlands to carry out comparative studies with native stingless bees, solitary bees, honey bees, and bumble bees (Roessink et al. 2011). Specifically, stingless bees in Kenya currently being studied include *Meliponula ferruginea* and *M. bocandei*, while in Brazil they include *Scaptotrigona postica* and *Melipona scutellaris*. The African honey bee (*Apis mellifera scutellata*) in Kenya and the Africanized honey bee (also *Apis mellifera scutellata*, but hybridized with European honey bees in the Americas) in Brazil are also study organisms. The results are expected to aid in understanding differences in sensitivity to various pesticides among stingless bees and honey bees in the tropics, compared to the western honey bee (*Apis mellifera mellifera*) and bumble bee (*Bombus terrestris*) found in the Netherlands. In addition, tests will be performed on solitary bees in Brazil and Kenya (e.g., *Xylocopa* spp.) after optimizing procedures for their rearing to ensure enough individuals are available to meet the testing requirements.

### **Opportunities for non-*Apis* bees to inform pollinator risk assessment**

Specific life history traits of non-*Apis* bees lend themselves to providing useful information for risk assessors. For example, solitary non-*Apis* bees, such as *Osmia* and *Megachile* spp., have a more restricted foraging area than honey bees and use of these solitary species in field testing scenarios may provide more confidence that the test bees are foraging (receiving exposure) from the treated (test) crops (Maccagnani et al. 2003, Zurbuchen et al. 2010). In typical field test scenarios, it is only feasible to apply the product to a limited area (e.g.,  $\leq 2$  ha.) of a bee-attractive crop., Compared to solitary species, honey bees forage over much larger areas (Visscher & Seeley 1982, Steffan-

Dewenter & Kuhn 2003), which consequently can be a challenging variable to control in field test scenarios.

In another example, managed non-*Apis* bees, also lend themselves to semi-field experiments by virtue that they may be less stressed than honey bees in an enclosed cage or greenhouse setting, and thus behave more “naturally” Table 3-1 provides a list of species that are available for toxicity testing, and also provides sources of information on their management. Further research on the use of these species would also inform the use of *Apis mellifera* as a surrogate for other non-*Apis* bees. Table 10-5 also lists available laboratory, semi-field, and field studies with representative groups of solitary and social non-*Apis* bee species.

Furthermore, because most non-*Apis* bees are solitary species, where single female bees build their nests, lay eggs, and forage for pollen and nectar to feed their offspring, the death of a foraging female or even her inability to provision her cells results in the cessation of her reproduction (Taséi 2002). Field kills of bumble bee queens early in the season represents a significant impact, as their death (as opposed to that of a worker) prevents the bumble bee colony from being established. When honey bee workers are killed in the field, the loss of these workers may, to a certain extent, be compensated by the colony and may mask the impact of field kills. Because field kills have an immediate impact on non-*Apis* bees located near treatment areas, use of non-*Apis* species in semi-field and field studies may be advantageous by leading to more robust risk assessment.

## **Conclusions**

It is clear that non-*Apis* bees play an important role in supporting diverse plant communities, and an increasingly important role in agriculture. They differ from honey bees in their biological characteristics, which consequently may make them subject to unique exposure routes (Tuell and Isaacs 2010, Brittain and Potts 2011), as well as unique challenges when it comes to risk management. Chapter 7 provides a very detailed discussion of specific biological, behavioral, or ecological traits – such as larval feeding behavior, foraging time and distance, and use of unique nesting materials – and how they

affect exposure risk. Chapter 13 outlines suggested techniques for mitigating risk to non-*Apis* bees, in light of their unique biology.

At the same time, some of these characteristics – such as their more limited foraging ranges and relatively unaffected foraging in enclosed areas – could be used to better assess the risks of pesticide applications for a wide range of pollinators, (including honey bees). See Chapter 9 for additional details on semi-field and field studies, and Chapter 10, Table 10-5 for a list of examples.

For several reasons, Workshop attendees believed it important to consider non-*Apis* bees among its discussions on pesticide risk assessment for pollinators, including: (i) the increased understanding of the value of non-*Apis* bees in commercial agriculture; (ii) the critical role they play in natural ecosystems; (iii) increased research being conducted with them; and, (iv) the potential value they may add to the understanding of potential risks from pesticides to these taxa. For these reasons the Participants of the Workshop considered when and how non-*Apis* bee species may be incorporated and considered in a pesticide risk assessment for pollinators.

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**Table 3-1.****Potential Non-*Apis* Bee Species for Use in Laboratory, Semi-field or Field Tests \***

<b>Species (common name)</b>	<b>Sociality</b>	<b>Region</b>	<b>References on management</b>
<i>Megachile rotundata</i> (Alfalfa leafcutting)	Solitary	Temperate North America, Asia	Mader et al. 2010
<i>Osmia lignaria</i> (Blue orchard bee)	Solitary	Temperate North America	Bosch & Kemp 2001, Mader et al. 2010
<i>Osmia cornifrons</i> (Japanese orchard bee)	Solitary	Temperate Asia, Europe	Sekita & Yamada 1993, Wilson & Abel 1996, White et al. 2009, Mader et al. 2010
<i>Osmia rufa</i> (Red orchard bee)	Solitary	Temperate Europe	Krunic et al. 1995, Bilinski & Teper 2004
<i>Osmia cornuta</i> (Hornfaced bee)	Solitary	Southern and Central Europe	Krunic et al. 1995, Maccagnani et al. 2003
<i>Amegilla chlorocyanea</i> (Blue-banded bee)	Solitary	Australia	Hogendoorn et al. 2006
<i>Xylocopa</i> spp. (Carpenter bees)	Solitary	Tropical (Brazil)	Freitas & Oliveira-Filho 2001, Freitas 2004
<i>Bombus impatiens</i> (Eastern bumble bee)	Social	Temperate (North America)	Readily available commercially. See also Evans et al. 2007, Mader et al. 2010
<i>Bombus terrestris</i> (European bumble bee)	Social	Temperate (Europe)	Readily available commercially. See also Evans et al. 2007, Mader et al. 2010
<i>Melipona beecheii</i> (stingless bee)	Social	Tropical (Central America)	Gonzalez & De Araujo Freitas 2005, Villanueva-Gutiérrez et al. 2005, Quezada Euán 2005, Quezada Euán & José Javier 2009
<i>Trigona nigra</i> (stingless bee)	Social	Tropical (Central America)	González & Medellín 1991a, 1991b
<i>Nannotrigona perilampoides</i> (stingless bee)	Social	Tropical (Central America)	González & Medellín 1991a, 1991b
<i>Trigona carbonaria</i>	Social	Tropical	Heard 1998, Heard & Dollin 1998b, Greco



(stingless bee)		(Australia)	et al. 2011
<i>Melipona subnitida</i> (stingless bee)	Social	Tropical (Brazil)	De Oliveira Cruz et al. 2005
Meliponini tribe (stingless bees)	Social	Tropical (Brazil)	Nogueira-Neto 1997
Trigonini tribe (stingless bees)	Social	Tropical (Brazil)	Nogueira-Neto 1997
<i>Meliponula bocandei</i> (stingless bee)	Social	Tropical (Africa, Kenya)	Kwapong et al. 2010
<i>Meliponula ferruginea</i> (stingless bee)	Social	Tropical (Africa, Kenya)	Kwapong et al. 2010

\* All of these species are either commercially available and/or they can be managed for crop pollination in various parts of the world. Analysis of data generated with these species would inform whether or which species may be an appropriate surrogate, and whether their use in pesticide risk assessment would be sufficient to support regulatory decisions and attendant protection goals.